DEVELOPMENT OF A CENTER ADAPTATION TOOL TO SUPPORT THE EN ROUTE/DESCENT ADVISOR COMPONENT OF THE CENTER-TRACON AUTOMATION SYSTEM

Modifications to the Adaptation, Validation, and Analysis (AVA) Tool and Recommendations for Required CTAS Changes

Prepared by

Cortland Systems, Inc.
Member of the Honeywell Team
for the NASA Advanced Air Transportation Technologies Program
December 18, 1998

Table of Contents

Index of Figures

Background

NASA Ames Research Center is currently engaged in the development of the En route / Descent Advisor (E/DA) portion of the Center/TRACON Automation System (CTAS). This controller tool will provide conflict probe and descent planning capabilities to support the controller's operational decision making process. As this tool supports critical controller decisions, it is essential that the representation of airspace characteristics and procedures be as accurate as possible.

The details in this report describe the design and development of enhancements to the Adaptation, Validation and Analysis (AVA) tool for the application to the En route / Descent Advisor portion of the CTAS system. The AVA tool has been under development, in support of the FAA, for the last four years. This development effort has covered both the Build 1 and Build 2 versions of the CTAS System. However, the Build 2 system does not yet include the E/DA portion of CTAS. Therefore, the capability to adapt the E/DA portion of CTAS is not currently supported by AVA.

Extensive use of the AVA tool for adaptation of the Build 1 and 2 CTAS systems has shown two primary benefits: 1) a significant decrease in the amount of time required to create an adaptation, and 2) an increase in the accuracy and performance of CTAS operation. Thus, the objective of the current effort was to use the existing AVA development as a foundation for building an initial E/DA adaptation tool. The intent was to provide NASA with a tool that increases the performance, accuracy and benefit of the E/DA controller tool, while decreasing the effort and resources required to develop, validate, and maintain E/DA adaptation data.

The remainder of this report is structured as follows: first, we will provide an overview of the analysis and design conducted for this effort. This includes a review of the missing adaptation functionality that is required to support the E/DA portion of CTAS, the design of the new adaptation data elements, and the design and testing of the new software. The identification of this missing functionality served as a blueprint for the development work that was completed and also helps to provide a commonly understood set of goals for the combined AVA/CTAS development effort to support E/DA functionality.

Next, we briefly describe the fact that we modified an existing D/FW adaptation as part of our software testing effort. The adaptation includes recent electronic data sources and adds the new data elements as designed for this project. Although the CTAS modifications that are needed to support these new data elements have not yet been developed, modifying the adaptation provides the CTAS development team with sample data files that can be used when designing the needed CTAS modifications.

Following this, we discuss some of the additional issues that need to be addressed. This includes a discussion of some modifications to the functionality that, if made, may prove useful for E/DA adaptation and operation as well as some recommendations for how CTAS can best be modified to handle the new data generated by the E/DA-AVA tool. Included with the CTAS modification suggestions is information pertaining to where the AVA changes are located within the ClearCase software configuration management system at NASA.

Design of AVA Enhancements for En route / Descent Advisor

Identification of Missing Functionality

In order to design the necessary enhancements to AVA to support the adaptation of the E/DA portion of CTAS, an analysis of the current CTAS/AVA System and the additional E/DA requirements was conducted. Fortunately, much of the adaptation data elements that are required for the E/DA portion of CTAS are also required for the TMA system. It is for this reason that AVA provides such a solid foundation for the development of an E/DA adaptation tool.

However, some additional adaptation data elements are still required to support the E/DA system, including Analysis Categories and Category Definitions for Departure and Over-flight traffic as well as Fix locations and Airway descriptions outside of the hosting ARTCC's airspace.

Adjacent ARTCC Overflight Route data

Currently, the adaptation data sets for CTAS include fix and airway data that is primarily considered to be local to the ARTCC for which the adaptation has been created. However, in order to effectively handle the conflict probe notifications and descent advisories, the CTAS system much be able to evaluate traffic that is further out (from the arrival airport) than is currently available. For example, CTAS needs to obtain trajectory information for aircraft outside the current ARTCC in order to probe for conflicts near the ARTCC boundaries. In addition, conflicts outside of the current ARTCC boundary should be considered in order to evaluate how actions inside the boundary will affect the sectors in those adjacent ARTCCs.

Thus, AVA needs to be modified to include additional airspace fixes outside of the host ARTCC's airspace and a definition of the fixes that comprise airways outside of the host ARTCC's airspace. Dependent on the design decisions that are made for NAS Route Processing in CTAS, we must consider that additional adaptation data may be required to support this functionality of E/DA in the future. However, that work is outside the scope of the current effort. The only CTAS software change that should be required for this element is an increase in the number of allowable fixes, as fix locations and airway definitions are already supported by CTAS. Please see the section on CTAS modifications (page 14) for more information.

AVA currently reads and processes the Adaptation Controlled Environment System (ACES) data within the ARTCC boundaries. Outside of the boundaries, however, there are some problems with the ACES data (i.e., incomplete routes, reversed-order fix locations, etc.). Therefore, a more accurate data set for fix/airway information outside of the ARTCC boundaries is needed for the purposes of E/DA. Thus, we conducted a brief investigation of alternative electronic data sources that could potentially benefit to the CTAS/AVA system for this Adjacent ARTCC Overflight Route data requirement. These data sources included Jeppesen data, the Digital Aeronautical Chart Supplement (DACS), as well as the existing NFDC data. More information about the modified airways data will be described below in the section entitled: *Adjacent ARTCC Overflight Route Adaptation Data*, on page 4.

Secondary Airport Arrival Processing

CTAS does not currently support meter fix adaptation for secondary airports. However, the lack of accurate secondary airport arrival route information could cause missed conflict alerts as well as many false alerts. Both of these events will render the E/DA system unacceptable by operational controllers and will impact the accuracy of the CTAS system.

The initial AVA capability for Secondary Airport Arrival Routing has been designed to be a phased approach to developing the adaptation data in conjunction with CTAS developments. Initially, the adaptation should be modified to enable the specification of meter fixes as well as meter fix crossing restrictions for satellite airports. However, in order to keep the CTAS system as flexible as possible, and to allow the adaptation to accommodate a greater number of secondary airports, regardless of size, it may be beneficial in the future to enable users to specify additional crossing restrictions. For example, by allowing the adaptation to define crossing restrictions to general-area airport arrival arcs and/or arbitrary line segments in space, the user would be able to define more general restrictions for larger amounts of airspace (such as the area encompassing a number of smaller airports). Doing so could potentially reduce the complexity of the adaptation effort, yet still allow the CTAS system to maintain a high level of accuracy.

It is expected that AK routes will be sufficient to provide detailed arrival routing information until a determination is made of NAS Route Processing requirements for CTAS and other supporting requirements. It is important to note that additional CTAS functionality will be required to utilize the current new adaptation data (secondary meter fix specifications) as well as any future enhancements (such as general-area arrival specifications and restrictions).

Generalized Crossing Restrictions

For both conflict probe and descent advisories, CTAS needs to compute each aircraft's trajectory according to the altitude and speed restrictions that define the airspace. General crossing restrictions are currently used in ATC operations, but CTAS currently only supports specific restrictions (such as Meter Fixes and Final Approach Fixes). If we consider that inter sector boundaries are essentially line segments between the two sectors, then CTAS needs to be able to compute the speed and altitude values of each aircraft as it's path crosses the associated line segment. Again, if the proper crossing restriction modeling is not in place, the system has a greater chance of causing missed alerts and generating false alarms.

Therefore, initial AVA capabilities are needed to accommodate generalized crossing restrictions for traffic. These generalized crossing restrictions, represented by line segments with associated altitude and speed values for the restriction, can be classified through the Aircraft Class indicator that is associated with the aircraft type in ACES data. Note that originally we expected that the generalized crossing restrictions would be defined for arrival, departure, and overflight traffic. Operationally, however, restrictions are only specified for arrivals and departures. As such, the code will be placed in AVA to allow specification of generalized crossing restrictions for overflight traffic, but should not be used until it is determined to be operationally meaningful. Note that satellite departures arriving at an adapted airport must meet the arrival airport restrictions and are therefore covered by the adaptation.

Design of New Adaptation Data Formats

After identifying the required enhancements for AVA to support the E/DA portion of CTAS, the next step in the process was to design the new adaptation data formats to accommodate the additional information. To minimize impact on the CTAS System, these data formats were designed to use existing CTAS conventions to the greatest extent possible and whenever appropriate. However, as mentioned above and described in greater detail below, certain CTAS code changes are required to accommodate the new adaptation data formats.

Adjacent ARTCC Overflight Route Adaptation Data

The first required addition to the adaptation database for E/DA was to enable the CTAS system to include airway and fix data that was outside of a CTAS-adapted ARTCC boundary. In order to complete this, our first step was to merge NFDC and ACES airway data into a common airway data set. With the addition of Victor and Jet airways from NFDC, we have significantly expanded the coverage of En Route airways in the adaptation data set (see Figure 1and Figure 2). Note that for this airways merge operation, we are using the ACES data for airway information that is within ARTCC boundaries. For any airway information located outside of the adapted ARTCC, NFDC data will be used in place of the ACES data.

Figure 1. Existing ACES airways data set for Dallas/Ft. Worth

Figure 2. There is a significant increase in data coverage when using the combined ACES and NFDC airways for route processing.

We have also significantly increased the number of waypoints within the adaptation. Previously, there were approximately 5,300 waypoints. Now, with the merged NFDC airways, there are now over 10,000 waypoints. To accommodate this large number of waypoints, the array size in both AVA and CTAS has been increased to 12,000. It remains to be seen whether or not the increase in number of waypoints has any negative impact on CTAS performance.

For the current effort, the addition of nation-wide airway and fix data was conducted with the restriction that the adaptation file formats *not* be changed. By enforcing this restriction, CTAS is able to use the new airway data without modification (except for the increase in the number of fixes). However, future work should include the addition of airway exit fixes for improvements in route processing accuracy. Considerations for this addition are discussed further in the CTAS Development Issues section of this report.

It is also interesting to note that Figure 2 demonstrates two problems that have been uncovered and fixed through our effort. As can be seen in the image, there are two regions of the airways structure that contain a heavy concentration of long straight lines. One set of lines extends from Washington State to Oklahoma while the other set extends from eastern Colorado to Mexico. Both of these sets of lines show cases in which the location of an airway fix was determined incorrectly due to name duplication. In the first case, a fix name was duplicated between NFDC data and ACES data. The fix name, ALW, is a valid fix in the national airspace system in Walla Walla, WA. However, the ACES adaptation data for Ft. Worth ARTCC also included a fix called ALW that was created for internal ACES use only. In this case, the ALW fix was used as a terminal area entry fix (a fix-pair) to properly establish automatic hand-off between Ft. Worth ARTCC and OKC approach control.

Since previous uses of the Ft. Worth ACES data did not require the data to be merged with a national dataset, this conflict was not found. With the new requirements for the current effort, however, a solution was necessary. Through coordination with the Ft. Worth ARTCC staff, the conflict was resolved by changing the name of the fix in the ACES data. Fortunately, since this fix was only used internally, it was not difficult for the automation staff to modify the fix name.

The second case of conflict occurred between two NFDC fixes. In this case, however, the conflict was a result of the way in which AVA parsed the NFDC fix data. The NFDC data contains fix information for the continental United States, as well as US territories and some areas of Mexico. As a result of this broad coverage over airspace controlled by different countries, name conflicts can occur. The NFDC data source provides a unique identifier for each fix to be used throughout the NFDC data files. The fix information provides both the commonly used fix name, as well as the NFDC-unique fix name. AVA had been using only the commonly used fix name, rather than the unique name. Thus, a conflict resulted between a fix in the US and a fix in Mexico. Once the NFDC unique name was utilized, this conflict was resolved.

A sample of data from the merged NFDC/ACES airways file, showing both the portion of the airway that is in the ARTCC as well as the NFDC portion (outside of the adapted ARTCC) is shown below. Note that the textual description of ACES/NFDC boundaries have been added for illustration purposes only.

```
#NAS jet airways file AVA generated

                          DALLAS_FT_WORTH

ROUTE       J4
ILM
FLO
CAE
IRQ
AJFEB
MGM
```

```
MEI
JAN
JAN271030
JAN271060
10376
JAN271072
69110
MLU315011
STAGE
EIC087033
EIC087025
EIC
LASSA260009
UIM095014
LIGRE
CVE
FUZ
MQP002003
ABI069050
ABI069038
ABI069017
ABI
ABI249050
HYMAN360009
MAF057023
MAF357004
INK
INK258015
10311
SFL360011
WHOLE
CONNE
EWM
SSO
BXK
MESSI
PKE
PIONE
RUSTT
CIVET
TNP
LAX
```

Everything between JAN and CONNE is within the ARTCC boundary

Figure 3. Modified airways data file sample

Secondary Airport Meter Fixes and Restrictions

As a result of the current effort, AVA now allows the user to identify specific meter fixes to be used as arrival processing fixes for secondary (satellite) airports. In addition to the specification of these meter fixes, the user can also specify crossing restrictions (speed and altitude) for these meter fixes through the use of the Crossing Restrictions capability described below.

The secondary airport meter fix adaptation is intended to increase the accuracy of arrival trajectory prediction in the horizontal plane. However, the specification of crossing restrictions will also increase the accuracy in the vertical plane. As mentioned earlier, in many cases we expect that the AK route will provide sufficient horizontal route information--the specification of meter fixes will provide anchors for the specification of crossing restrictions. However, some cases may be identified in which the AK data does not provide sufficient routing information. If this is the case, the meter fixes can be used by CTAS to establish arrival routing into the secondary airport.

The secondary_meter_fixes file resides in the Site_data/system/ directory. The adaptation data format for the secondary_meter_fixes file uses the keywords `airport` and `meter_fix`. The `airport` keyword is followed by the name of the secondary airport for which meter fixes will be specified. This keyword and parameter must appear on a separate line before the `meter_fix` keyword. Note that one or more `meter_fix` keywords can be specified on a separate line with each `meter_fix` keyword being followed by the name of the fix that is to be a meter fix for the secondary airport. An example of the data format used for the secondary meter fix designation is shown below in Figure 4.

```
#secondary_meter_fixes AVA generated
                                      ZDV_TMA
airport            COS

meter_fix                                 QUAIL
meter_fix                                 LARKS
meter_fix                                 PUB


airport            ASE

meter_fix                                 SKIER
```

Figure 4. Secondary airport meter fix data format.

The crossing restrictions for the secondary meter fixes are also kept in the Site_data/system/ directory in a file called ‘crossing_restrictions.’ Although for primary airports, the fixes and crossing restrictions are kept in the same file, we separated the two for this project with the logic that it is better for CTAS processing if all of the generalized crossing restrictions are kept in the same file. An example of the data format for the secondary meter fix crossing restrictions is shown below in Figure 5. The individual tokens are used to more precisely define the restriction.

```
CROSS RESTRICTIONS

restriction            SKIER_kl
route                  NONE
location               NONE
ac_type                PISTON
airport                CYS
start_time             0
duration               10000
altitude               11000
speed                  310
phase                  DEPARTURE
ac_classes             kl
```

```
boundary_type                    FIX
     waypoint        SKIER
```

Figure 5. Crossing restriction data format for secondary airport arrival fix

Using AVA, the user can set multiple attributes for the fix crossing restriction, resulting in the creation of an entry, as shown above, in the Site_data/system/crossing_restrictions file with the following tokens:

`restriction`	The name of the restriction. Currently, this name is set by AVA. However, with facility input, a more meaningful naming convention could be devised.
`route`	Currently not used, but can be used in the future to specify if a restriction applies to a single Jet or Victor route (which, for example, would allow aircraft with "fly direct" approvals to not be restricted).
`location`	Again, this token is not currently used, but stands as a place holder for future functionality.
`ac_type`	The type of aircraft (Jet, Turbo-Prop, or Piston) that is restricted. AVA also allows for any combination of the three types, as well.
`airport`	The airport for which the restriction applies
`start_time`	This token is not currently used, but future work could allow uses to specify dynamic restrictions which begin at a set time
`duration`	Again, this token is not currently used, but combined with `start_time`, users can create dynamic restrictions.
`altitude`	The altitude of the restriction, in feet. Note that the altitude restriction is further defined by the `phase` token. If the flight phase is an arrival, then the altitude restriction is an "at or below" restriction, meaning that the arrival aircraft must cross this fix at or below the defined altitude for descent into the airport. A departure flight phase results in an "at or above" altitude restriction.
`speed`	The crossing speed restriction, in knots.
`phase`	The phase of flight for which the restriction exists (arrival or departure).
`ac_classes`	The single letter identifier, defined and used by the local facility, to categorize aircraft (i.e., military flight v. general aviation, performance characteristics, etc.). A restriction can apply to multiple aircraft classes.
`boundary_type`	The type of crossing restriction. In this case, it is a fix crossing restriction. However, other restriction types (lines, arcs, etc.) use the same general format. The `boundary_type` token identifies these restrictions.
`waypoint`	The name of the NAS waypoint used for the restriction.

Although discussed separately here in the document, note that the crossing_restrictions file contains the information for *all* of the generalized crossing restrictions defined in the adaptation. These additional crossing restrictions (sector boundaries, arbitrary line segments, and arbitrary arcs) are described in the next section, below. Also, note that CTAS code changes will be required in order to read and use this new adaptation data. A discussion of these code changes is included in the Required CTAS Modifications section later in the document (page 14).

Generalized Crossing Restrictions

In this initial effort we have provided the entry capability for specifying sector boundaries (the line segments between two sectors) and the crossing altitude and speed restrictions associated with those boundaries (see Figure 6). These crossing restrictions are tied to aircraft arriving at or departing from specific airports within the ARTCC.

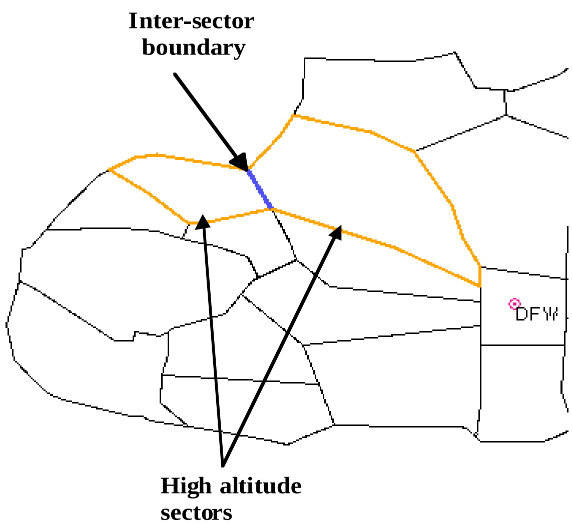

Figure 6. Generalized crossing restrictions for arrival aircraft can be set for the line segments that exist between two adjacent sectors

In addition to specifying a pre-defined sector boundary as a crossing line, it is also possible to specify arcs from a point and/or arbitrary line segments for more generalized crossing restriction definitions. Figure 7 shows a conceptual example of both of these types of crossing restrictions. Note that they also apply to aircraft that are either arriving to or departing from a specific airport.

By allowing the user to specify crossing restrictions on more arbitrary regions of the airspace, the trajectory modeling used for the conflict probe can take into account additional procedural restrictions that may be in place at a particular facility. In the figure below, consider what would happen in the current system if aircraft A and B were initially at the same altitude. The conflict probe is designed to predict each aircraft's trajectory and determine if a conflict will occur. Without knowledge of the arbitrary line segment crossing restrictions, the conflict probe would likely alert the controller of a potential conflict. However, by including the arbitrary line segment crossing restrictions in the adaptation, the aircraft trajectory model can take advantage of the operational knowledge that, in this case, the crossing restrictions that apply to each aircraft would place them at different altitudes and, therefore, they will not be in conflict. Although some level of alert might still be desirable, as a backup measure, the probability that A and B will be in conflict is much lower because of the operational restrictions that are known to be in place.

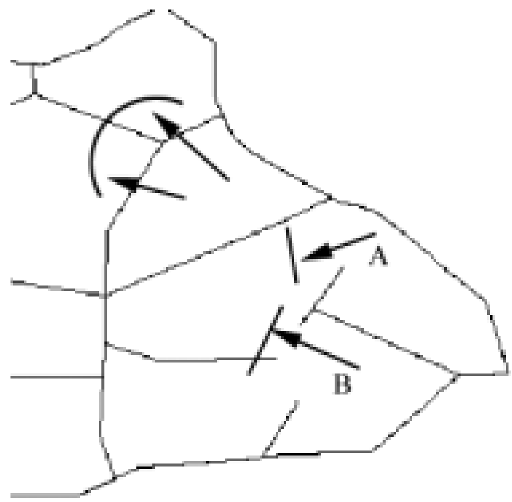

Figure 7. The AVA tool also allows crossing restrictions to be placed on arcs from a point and/or arbitrary line segment. Doing so further increasing the accuracy of the airspace representation

Examples of the data formatting used for the specification of the different types of generalized crossing restrictions are shown below. Examples of the generalized crossing restrictions for sector boundaries, arbitrary line segments, and arcs have been separated below into Figure 8, Figure 9, and Figure 10, respectively, for illustration purposes. The specific example for secondary arrival fixes was shown above in Figure 5. As mentioned earlier, the crossing_restrictions data for all of the generalized crossing restrictions (secondary meter fixes, sector boundaries, lines, and arcs) is kept in the same file.

The main difference in the data format for sector boundary crossing restriction (shown below in Figure 8) from the secondary meter fix restriction is in the addition of the `sector_from` and `sector_to` tokens and that the `boundary_type` is set to line (the line between two sectors). The `sector_from` and `sector_to` tokens are used to describe the direction of traffic that will be affected by this current restriction. The multiple `start_node` and `end_node` tokens simply define the individual smaller line segments that are combined to make up a longer shared boundary between sectors. The AVA tool automatically calculates the number and location of all the nodes for the entire boundary shared by the two selected sectors. Note that the "node" locations that are written out by AVA represent the node information in latitude and longitude (HHHMMSSS) format.

```
restriction            sec19_sec20_kl
route                  NONE
location               NONE
ac_type                PISTON
airport                CYS
sector_from            19
sector_to              20
start_time             0
duration               10000
altitude               11000
speed                  310
phase                  DEPARTURE
ac_classes             kl
boundary_type                  LINE
        start_node     391037     1084528
```

```
end_node        392742     1092604
start_node      394817     1094232
end_node        396800     1094338
```

Figure 8. Sector boundary crossing restrictions (line segment) as indicated with "sector_from" and "sector_to" designators

The arbitrary line segment restriction looks the same as the sector boundary crossing restriction except for the fact that the `sector_from` and `sector_to` tokens are not used, as shown below in Figure 9.

```
restriction             line_167_423_kl
route                   NONE
location                NONE
ac_type                 PISTON
airport                 CYS
start_time              0
duration                10000
altitude                11000
speed                   310
phase                   DEPARTURE
ac_classes              kl
boundary_type                   LINE
        start_node      391037     1084528
        end_node        392742     1092604
        start_node      394817     1094232
        end_node        396800     1094338
```

Figure 9. Arbitrary line segment crossing restriction data format

The crossing restriction for an arbitrary arc is shown below in Figure 10. The arc restriction is indicated by the `ARC` value for the `boundary_type` token and contains information on the center, radius and start and stop angles of the arc. The `center` is indicated by a latitude/longitude position, the `radius` in nautical miles, and the `start_stop_angles` defines the angles, from true north, used to determine the location for each of the end points. Thus, in the example below, a 30-degree arc, has been placed 16 nmi north of the center point.

```
restriction             arc_270_282_76_op
route                   NONE
location                NONE
ac_type                 PISTON
airport                 ASE
start_time              0
duration                10000
altitude                15000
speed                   290
phase                   DEPARTURE
ac_classes              op
boundary_type                   ARC
        center    381037     1034528
        radius    16
        start_stop_angles       -15     15
```

Figure 10. Arc-based crossing restriction data format

Design of Software Enhancements

The final portion of the design phase of this effort was the software design. The AVA software enhancements were designed in conformance with the existing object oriented software approach that was used for the previous versions of AVA. The use of an object oriented software design allows easier re-use of existing code – including the possibility of re-using AVA code for inclusion in CTAS. Examples of such re-use possibilities include the code that was developed in AVA to read the new adaptation files and access new adaptation data.

In addition to the software design itself, a ClearCase configuration management plan, coordinated with both NASA and Sterling Software managers, was also developed. In order to effectively merge the created software enhancements, Cortland Systems has created a new branch (called *brinton_pr03766*) with all of the necessary software modifications. We have also filed the necessary CTAS Problem Reports (PRs) indicating which changes are necessary and why. The software modifications will be delivered on this separate branch, allowing NASA to conduct any additional testing or coordination desired before actually checking in the changes.

E/DA-AVA Software Development & Test

The AVA software was enhanced to address the data requirements as identified in the Research Task Order description and our identification of missing functionality. The current effort resulted in an initial version of AVA capability to satisfy each of the adaptation requirements. Note, however, that additional AVA capability beyond this initial level will eventually be required to provide higher levels of adaptation automation assistance (ease of use) and to provide higher levels of accuracy in the representation of airspace characteristics and operational procedures.

Developed Software

For each adaptation requirement, software was developed for the following AVA modules:

- Adaptation Data File Input/Output
- Adaptation Data Validation
- Electronic Data Source Processing (as appropriate)
- User Interface
- Chart Change Update

Aside from the CTAS modification to handle an increased number of waypoints, only AVA software was developed under this effort. Additional CTAS software changes will be required to allow the use of the new adaptation data elements. Suggestions for these modifications will be discussed below.

Initial Software Testing

The final software sub-task of this effort was the testing of the AVA software tool; any additional enhancements, capabilities, or bug fixes that were required to support the initial capabilities as defined in the original proposal were identified and completed. In addition, system execution testing was conducted to ensure correct operation of the tool, including processing of input data sources (ACES, NFDC, etc.), validation of adaptation data elements and output of the E/DA adaptation data in the appropriate format.

Further testing can be conducted by actually running the E/DA portion of CTAS with the adaptation data sets that will be generated using the AVA tool. In preparation for those tests, a sample adaptation (D/FW ARTCC) was developed on-site with NASA input.

Dallas/Ft. Worth ARTCC Airspace Adaptation

In order to test the new functionality developed for the AVA tool, an existing CTAS adaptation for D/FW ARTCC was modified. Although this adaptation included using the most recent electronic data sources, note that the scope of the current effort did not include the continued maintenance of the sample E/DA adaptation after delivery. The adaptation was simply modified to demonstrate the new functionality in AVA. The generated data files were included on the ClearCase branch used for this project (*brinton_pr03766*).

It is also important to point out that the sample adaptation was completed without the necessary CTAS software enhancements being developed. As such, it was not possible to "operationally" evaluate (through CTAS) the effects of the new adaptation elements. The work is still of great benefit, however, as the development of the files will allow the CTAS software enhancement process to be conducted with the availability of sample adaptation data. Cortland Systems has developed the software that is used in AVA to read and store the adaptation file data in a manner that facilitates re-use of the code in CTAS itself whenever possible. This was done to remain consistent with the current Joint Development Program efforts on CTAS, in which a common set of common adaptation libraries for use by both AVA and CTAS are being developed. In order to accommodate the new adaptation data, we will briefly discuss some of the recommended changes needed for the CTAS system, below.

Additional Issues

As has been stated above, the work conducted for the current effort applies only to the AVA system (i.e., the design and development of the AVA tool itself). This work focused on modifying the AVA tool to be capable of processing the additional electronic data sources, receiving user input, performing a limited set of adaptation data validation checks, and writing adaptation data files for the new adaptation data elements identified.

This initial effort was focused on developing the capability to read and use adjacent ARTCC route data, specify secondary airport meter fixes and crossing restrictions, and to specify more general crossing restrictions such as inter-sector boundaries (line segments between two sectors) and arcs from a point. Some additional modifications may prove to be useful future enhancements to the AVA tool, and are worth noting.

First, it would be helpful to allow users to specify more general-area airport arrival arcs and accompanying restrictions. For satellite airport arrival processing, a general-area airport arrival arc, if it is operationally meaningful, could be used to encompass a larger number of airports within a more general specification of shared restrictions, thereby potentially reducing the complexity of building and maintaining the adaptation (see Figure 11, below).

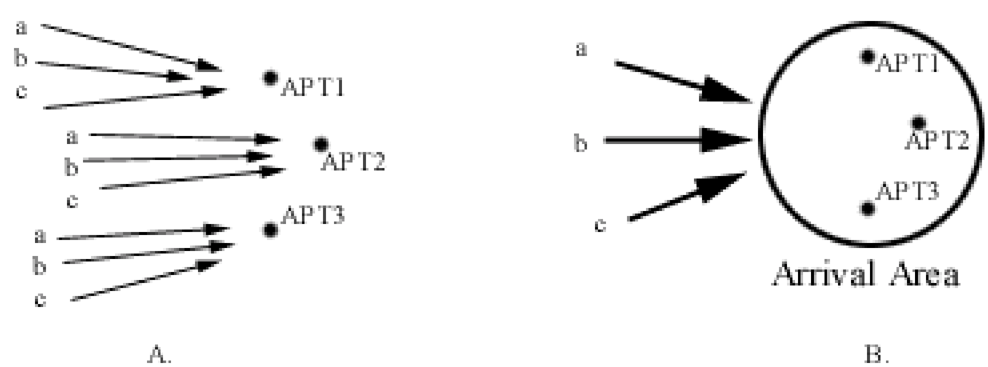

Figure 11. Similar restrictions (a, b, and c) can be applied to multiple airports if they are contained within a more generally defined arrival area.

Second, by creating analysis categories and category definitions for overflight and departure aircraft, the additional state information can be used to better compute aircraft routes and to allow E/DA to function properly. Note that for this initial effort, the file templates for these analysis categories and category definitions have been created. However, it is not currently possible to modify these files using the AVA tool.

Required CTAS Modifications

Most of the software that has been delivered as part of this effort consists of software modifications to the Adaptation, Validation and Analysis (AVA) tool. However, some modifications to CTAS itself have been made as well. All software additions and modifications have been integrated into the version of AVA or CTAS in the ClearCase source code Configuration Management (CM) system at NASA Ames Research Center. Appropriate CTAS software development procedures were followed during this effort. This work has been conducted under Problem Report ARCpr03766 in the DDTS bug tracking system that is used for CTAS.

So as to avoid any conflict with work being conducted on CTAS and/or AVA by other organizations, the software developed under this effort has been delivered on a separate software branch in the ClearCase CM system (branch label: *brinton_pr03766*). Note that the software on this branch is compatible with the *nasa_branch* baseline of CTAS and AVA only as of the date of delivery, December 18, 1998. Since the software has not been integrated into the nasa_branch, any changes made to the nasa_branch may cause incompatibilities with this software. It is suggested that these modifications be merged into the nasa_branch as soon as possible.

The following sections provide discussion of issues and suggestions for use of the new adaptation data elements that have been designed and developed through the conduct of this project. The issues and suggestions have been grouped by the new adaptation data items.

Outside ARTCC Airways and Fixes

The new adaptation data items for Outside ARTCC Airways and Fixes have been developed to minimize the CTAS modifications required for their use. The additional airway data has been added to the existing adaptation files, nas_aways_j and nas_aways_v. The additional waypoint data has been added to the existing adaptation file nas_waypoints. In this manner, E/DA is able to use the Outside ARTCC data without significant modifications.

The one CTAS change that is required to be able to use this Outside ARTCC Airway and Fix data is an increase in the maximum number of allowable fixes in CTAS. The previous size of the Waypoint array in CTAS was 6500. This array size was increased to 12000 by changing the `MAX_NAS_WAYPOINTS` parameter in the ctas_defs.h file.

There was some discussion at the Interim Meeting regarding the need for adaptation of airway exit fixes. This was not done in this initial project, as it would have required a format change. In addition, the necessary source data for airway exit fixes is only available within the ARTCC from ACES data. Since there is no airway exit fix data available outside the ARTCC, CTAS will be required to compute the best airway exit fix when the arrival airport falls outside the ARTCC. Rather than complicate the adaptation with airway exit fixes inside the ARTCC, it is suggested that CTAS compute the appropriate airway exit fix in all cases. However, if adaptation data for airway exit fixes is desired, this could be accomplished with new data structures and processing logic in both CTAS and AVA.

Secondary Airport Meter Fixes

The work that has been conducted for the development of adaptation data files and software for Secondary Airport Meter Fixes results in the creation of a new CTAS adaptation data file. Software modifications to CTAS will be required to use this new data.

Through the AVA software modifications that have been implemented, new data structures and subroutines for file input of the secondary_meter_fixes file have been written. This software is located in the following files on the *brinton_pr03766* branch:

/vobs/ava/src/adel/adel_satellite.h

/vobs/ava/src/ad/ad_CTAS_SatelliteMeterFix_File.H

/vobs/ava/src/ad/ad_CTAS_SatelliteMeterFix_File.C

Note that a separate structure for the secondary airport meter fixes was implemented in AVA. However, it is probably more appropriate for new fields to be added to the existing `Satellite_airport_st` in CTAS. The new fields needed are:

```
int        number_of_meter_fixes;
int        meter_fix[MAX_FEEDER_GATES];
```

The software subroutine that has been written to read in the data from the secondary_meter_fixes file is called `CtasSatelliteMeterFixFile::Read()` in the ad_CTAS_SatelliteMeterFixes_File.C source code file.

One of the issues that must be addressed in the use of the new data from this file is whether or not the trajectories that are generated for arrivals to secondary airports should be forced to cross the secondary airport meter fixes. If the secondary airport is located inside the ARTCC airspace, the AK route **should** give accurate information regarding the arrival route of the aircraft. An appropriate approach may be to use the AK route if it is available, and if the secondary airport is located inside the ARTCC. It may be appropriate to force the aircraft to cross one of the meter fixes if either of these conditions are not met.

Another consideration for the generation of trajectories to secondary airports in the use of the crossing restrictions that are placed on the secondary airport meter fixes. Even if the trajectory will not cross directly over one of the meter fixes, it may be appropriate to utilize the crossing restriction for the nearest meter fix, and create a pseudo fix on the AK route.

To simplify the adaptation requirements for CTAS, the EDA version of AVA has been designed in this effort so that adaptation of secondary airport meter fixes is not required for all secondary airports. The addition of adaptation for secondary airport meter fixes will improve the trajectory accuracy for arrivals to secondary airports. However, the majority of secondary airports have very low occurrence of IFR arrivals. Thus, it would not be worth the adaptation effort to add secondary airport meter fixes for these airports.

CTAS should not be coded with an assumption that meter fixes have been adapted for secondary airports. Thus, the route generation logic in CTAS should use the meter fixes if they are adapted. If they are not adapted, logic to create a pseudo-meter fix on the trajectory should be used.

Generalized Crossing Restrictions

The Generalized Crossing Restrictions adaptation data that has been developed through this effort will provide significant new capabilities for trajectory generation to E/DA, as well as potentially to TMA and FAST. Whereas crossing restrictions in CTAS to date have been tied to specific adaptation elements (like primary airport meter fixes), speed and altitude crossing restrictions can now be implemented generically.

As described above, data structures and adaptation data file input routines have been implemented in the EDA version of AVA and are available for use in CTAS. This software is located in the following files on the *brinton_pr03766* branch:

/vobs/ava/src/include/adapt.h

/vobs/ava/src/ad/ad_CTAS_CrossRestrictions_File.H

/vobs/ava/src/ad/ad_CTAS_CrossRestrictions_File.C

The new data structures can be found in the file:

/vobs/ava/src/include/adapt.h

and are listed below:

```
Boundary_type
Boundary_area_type
Fix_boundary_st
Line_boundary_st
Arc_boundary_st
Crossing_restriction_ava_st
Crossing_boundary_st
Crossing_boundary_list_st
```

The software subroutine that has been written to read in the data from the crossing_restrictions file is called `CtasCrossRestrictionsFile::Read()` in the ad_CTAS_CrossRestrictions_File.C source code file.

Once the crossing restrictions data has been read into CTAS, considerations exist for the use of the data. It is important that CTAS be coded to search through the crossing restrictions data for **all** crossing restrictions that apply to an aircraft or trajectory. There may be multiple crossing restrictions of multiple types (arc, line, sector boundary and fix) and multiple flight phases (arrival and departure) that apply.

Note that a detailed investigation of the Trajectory Synthesis (TS module) modes that are currently available has not been conducted. However, the TS is currently undergoing a redesign that should result in TS modes that can accept multiple, generic crossing restrictions.

Conclusion

This report described the results of an effort to develop an initial Center Adaptation Tool to support the E/DA portion of CTAS. The purpose of developing such a tool is to reduce the time that is required to develop adaptation data for the E/DA software, and to improve the accuracy and performance of the CTAS system. The E/DA portion of the CTAS system is designed to provide state-of-the-art conflict probe and descent planning capabilities to support the controller's operational decision making process. Because the E/DA tool will support mission-critical controller decisions, it is essential that the representation of airspace characteristics and procedures be as accurate as possible. Therefore the AVA tool, developed for the CTAS Build 1 and Build 2 systems, provided a solid basis upon which to develop the new functionality.

New adaptation elements such as Adjacent ARTCC Overflight Route data, Secondary Airport Arrival Processing, and Generalized Crossing Restrictions were added to the adaptation data set already created by AVA. Additional enhancements to the AVA software to accommodate these adaptation elements (such as the ability to effectively merge ACES and NFDC airways databases) were also developed. It was noted that many of the new adaptation elements require modifications to the CTAS software. Although the actual CTAS modifications were beyond the scope of this initial effort, recommendations for implementing the software changes were described.

In addition, we have modified an existing D/FW adaptation to include the new functionality available through AVA. This adaptation was modified in order to both test the initial functionality provided in the AVA tool as well as to provide the CTAS development team with a sample set of adaptation data, from which the required CTAS modifications could be designed.

The modifications made to the AVA tool to support the E/DA requirements can significantly increase the accuracy and reliability of the E/DA tool. By building the means to input additional, operational data (such as secondary airport arrival fixes, generalized crossing restrictions, and a national airway and waypoint database) into the adaptation, E/DA will have a more complete “body of knowledge” from which to draw critical information to determine an aircraft’s current state and predicted flight path. The result will be a system that uses a much more precise representation of the airspace and is, therefore, more finely tuned to the expectations of the operational controllers.